ENVIRONMENT AGENCY

GOOD PRACTICE GUIDELINES ANNEX TO THE ENVIRONMENT AGENCY HYDROPOWER HANDBOOK

THE ENVIRONMENTAL ASSESSMENT OF PROPOSED LOW HEAD HYDRO POWER DEVELOPMENTS

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1) INTRODUCTION

The number of hydropower schemes submitted to the Environment Agency has increased significantly over the last few years from less than 20 per year to more than 100 per year.

This annex to the Environment Agency Hydropower Manual is based on work undertaken jointly by the Environment Agency and the British Hydropower Association (BHA) and funded by the Department for Trade and Industry (DTI) in 2006. The aim of the work was to provide Good Practice Guidance to supplement the Hydropower Manual on aspects that most often cause difficulty with hydropower proposals. Four studies were commissioned:

1. An Environmental Site Audit (ESA) check list guide to assist in the initial environmental assessment of small hydro schemes.
2. How to establish the acceptable minimum flow in the depleted reach.
3. Monitoring flows abstracted by a hydropower scheme.
4. How to protect fish.

The results of these studies have been supplemented by further input from the Environment Agency and BHA. Detailed technical data related to flow measurement has been removed to an Appendix at the end of the annex.

This Good Practice Guidance was developed for low head hydropower, but the principles may apply to high head hydropower run of river sites.

The Environment Agency has wide ranging responsibilities set out most particularly in the Environment Act 1995, Water Resources Act 1991, Land Drainage Act 1991, Salmon and Freshwater Fisheries Act 1975 and the Water Framework Directive (WFD) which came in to operation in 2004. Section 4 of the Environment Act requires us, in discharging our functions, to contribute to the objective of achieving sustainable development.

The Environment Agency has statutory responsibility for flood management and defence in England and Wales. The Environment Agency advises Local Planning Authorities and applicants on flood risk from new development. Certain types of work affecting watercourses also require flood defence / land drainage consent from the Environment Agency.

This Guidance describes:

- baseline indications of hydropower potential that may be possible on a site while taking account of environmental concerns
- additional environmental factors that will need to be protected in some circumstances, and those that may, upon local inspection, be found to not apply. Where this is the case, there may be greater power potential at that site.

Some environmental aspects have to be satisfied as part of the developer's scheme and costs. Others can be met by wise site choice and application of best design principles that are available. There are some places where we believe the current high environmental status such as designated European sites means that the risks inherent with hydropower are likely to be unacceptable and we have incorporated advice accordingly. We also highlight the potential for cumulative impacts that would need to be addressed in some places.

There has been little monitoring of the ecological impacts of low head hydropower schemes. The Environment Agency will undertake a programme of work to investigate these impacts, but this is likely to require a number of years data pre and post hydro installation.

This Good Practice Guide will also require regular revision in the light of operational experience.

This guidance is for application on existing impoundments (weirs) and may affect existing or proposed hydropower generation.

The recommendations that follow were developed for Low head hydropower schemes – weirs usually less than 4 metres high – but the principles may apply to High Head hydro schemes .

Any proposals for new impoundments would be required to undertake more detailed Environmental Impact Assessments.

2) ENVIRONMENTAL SITE AUDIT (ESA)

An Environmental Site Audit (ESA) check list guide was developed to help identify hydro schemes that are not expected to pose environmental problems, those that require more detailed investigations, or may require an Environmental Impact Assessment (EIA). The procedure makes the licensing process transparent, efficient and technically sound. It is based on the main environmental functions of a river that need to be addressed in each case. The information required to carry out the audit is easy to acquire and developers should be able to initially consider the process themselves. Specific issues identified for a particular site may require further investigation or clarification and a series of notes offer guidance on the likely issues that may arise. In some cases there will be aspects that need to be investigated further. Where the check list indicates that further work may be required this should be discussed with the relevant regulator.

The Environment Agency and other regulators will consider the check list guide provided by the applicant and indicate whether they agree with the developer's assessment, or indicate where further information may be required.

The ESA covers the following areas in individual checklists:

- Water resources
- Conservation
- Chemical and physical water quality
- Biological water quality
- Fisheries
- Flood risk
- Navigation

The seven checklists are reproduced in the remainder of this section. In each case the checklist is broken down into a series of questions. If the green box is correctly ticked no further action will normally be required. If the red box is ticked the associated note to that question needs to be consulted for guidance on additional work that needs to be done to address the issue. All of the checklist notes are either below the checklist or on the page following.

The guidance does not cover local authority planning issues or heritage aspects of a development. Developers will need to satisfy these regulators separately.

tick box YES	tick box NO	A Water Resources Checklist	Note No.
		Is the scheme non-consumptive i.e. will 100% of any water abstracted be returned to the water course from which it was taken?	1
		Is the scheme being built on existing infrastructure?	2
		Will the turbine be placed directly within the weir / water course rather than in a separate channel?	3
		Is there a flow-depleted channel?	4
		Is there a flow-depleted weir?	4
		Is it intended to increase the height of the impoundment?	8
		Do surveys reveal any existing abstractions, including unlicensed ones, which will be derogated by the proposal? (1)	5
		Is there an Environment Agency gauging station in the depleted reach or nearby that is likely to be affected by the scheme?	6
		Will the developer accept derogation consent within the proposed licence?	7

All green boxes ticked require no further action.

Any red boxes ticked require further action, as outlined in the attached notes.

Notes:

1. Hydropower schemes are usually non consumptive abstractions, i.e., they normally discharge the water back into the same reach of the river. If the abstracted water is to be discharged into a different reach or river, the impact of the augmentation on that reach or river needs to be assessed. This is in addition to the impact of the flow depletion on the reach or river from which the water is abstracted. The licence requirements for hydropower are sometimes complex. Further information is provided in sections 3, 4, 5.

2. If new infrastructure is to be built, an impoundment licence or change in licence condition may be needed. The details will depend on what exactly is going to be built. A discharge consent and/or a flood defence consent may be required for the proposed works. Planning permission may be required. A flood risk/consequence assessment may be required in support of the flood defence/land drainage consent application and the planning application.

3. If the turbine is located directly by or within the weir, only an impoundment licence and a flood defence consent may be required, but not an abstraction licence. Flow depletion may not have to be considered, if there is no depleted reach, but other impacts on the river flow may need to be examined. The details of such a scheme need to be discussed with the relevant Environment Agency Area office.

4. In most cases, the turbine will be located on, or adjacent to, a man-made channel (leat) or pipe, to which the water is diverted from the main river. In such cases, an abstraction licence and a flood defence consent will be required, and the impact of the flow depletion on the reach and any parallel distributaries and/or weirpools need to be considered. (See note 1 and sections 3 and 5).

   If the water for hydropower is taken through a channel that is physically separate from the water course there will be a depleted reach in the main watercourse.

If the water is abstracted immediately upstream of a weir and returned immediately downstream, only the weir has a depleted flow, which may affect the aesthetic appearance of the weir, weirpool morphology and ecology and fish passage. Further guidance is provided in sections 3, 4 and 5.

Detailed drawings of the proposed hydropower scheme including the abstraction and return point are required. The ecological value of the deprived reach is important in determining the proportion of flow that can be used for hydropower. The Environment Agency advises developers to avoid schemes that cause a depleted reach, as the necessary mitigation measures will limit the power potential of the scheme.

5. Any abstractions from the depleted reach need to be considered. The exact volume, time and protected status of such abstractions need to be checked (see Water Act 2003). Information on abstractions is available from the Environment Agency Area office.

6. If the answer is yes, the details of the case will need to be discussed with the appropriate Hydrometrics team. Re-location of the abstraction/discharge may need to be considered.

7. The Environment Agency may wish to incorporate a condition within the abstraction licence which reserves a volume for future upstream licensing or improvement to fish passage. The quantity will depend on the location of the site within the catchment, the risk to fish passage, including aspirations for future improvements, the potential for increased future water demand upstream and the time limit of the licence. The quantity will be in accordance with Catchment Abstraction Management Strategies (CAMS) assessments and ecological and fish passage needs.

8. If the impoundment is to be increased or altered, then an impoundment licence will be required from the Environment Agency.

tick box YES	tick box NO	B Conservation Checklist	Note No.
☐	☐	Is the scheme within, or likely to have an impact on a Site of Special Scientific Interest (SSSI)?	9
☐	☐	Is the scheme within, or likely to have an impact on a Special Area of Conservation (SAC)?	10
☐	☐	Does the scheme have any impact on a Special Protected Area (SPA)?	11
☐	☐	Does the scheme have any impact on a National Nature Reserve?	12
☐	☐	Does the scheme have any impact on a Local Nature Reserve?	13
☐	☐	Does the scheme have any impact on an Area of Outstanding Natural Beauty (AONB)?	14
☐	☐	Does the scheme have any impact on a National Park?	15
☐	☐	Does the scheme have any impact on a Conservation Area?	16
☐	☐	Have formal ecological surveys been carried out on the site?	
☐	☐	Does the scheme take appropriate account of protected species (not fish) that may live at the site or elsewhere in the catchment?	17

All green boxes ticked require no further action.

Any red boxes ticked require further action, as outlined in the attached notes.

Notes:

9. A map of all UK SSSI sites is available from Natural England (www.natureonthemap.org.uk) or Countryside Council for Wales (CCW). Natural England or CCW needs to be formally notified of any works that may damage a SSSI. Informal contact with the relevant area office prior to formal notification is encouraged.

10. SACs are protected under the EU Habitats Directive. A map of all UK SAC sites is available from Natural England (www.natureonthemap.org.uk). Natural England needs to be formally notified of any works that may damage a SAC. Informal contact with the relevant area office prior to formal notification is encouraged.

11. SPAs are protected under the EU Birds Directive. A map of all UK SPA sites is available from the JNCC (www.JNCC.gov.uk).

12. A map of all UK national nature reserves is available from Natural England (www.natureonthemap.org.uk). National Nature Reserves are managed by different authorities. Advice should be sought from the relevant authority or from the NE/CCW area team.

13. A map of all UK local nature reserves is available from Natural England (www.natureonthemap.org.uk). National Nature Reserves are managed by different authorities, including local governments. Advice should be sought from the relevant authority or from the Natural England area team.

14. A list of AONBs is available from the Countryside Agency. Compliance of the scheme with the objectives of landscape protection may need to be sought from the relevant authority.

15. Each National Park has its own authority. Approval of the scheme by the National Park authority may be required.

16. Conservation areas are designated by local governments. Approval of the scheme by the local conservation officer may be required.

17. A list of protected species can be found on Defra's website (http://www.defra.gov.uk/wildlife-countryside/cl/habitats/index.htm).

tick box		C Chemical & Physical Water Quality Checklist	Note No.
YES	NO		
☐	☐	Will the scheme discharge the abstracted flow entirely back into the same watercourse?	1
☐	☐	Will pollutants be discharged into the river during construction and/or operation of the scheme?	18
☐	☐	Are there existing licensed pollutant discharges into the depleted reach?	19
☐	☐	Is the scheme likely to cause significant algal growth in the depleted reach?	20
☐	☐	Is the scheme likely to significantly increase river turbidity?	21
☐	☐	Is there an Environment Agency water quality monitoring point in the depleted reach or downstream?	22
☐	☐	Has a chemical river quality status been defined for the depleted reach?	22
☐	☐	Is deterioration of chemical status expected at the nearest downstream monitoring point?	23

All green boxes ticked require no further action.

Any red boxes ticked require further action, as outlined in the attached notes.

Notes:

18. Developers should not use toxic chemicals for maintenance, and should prevent spillages. Discharge of silt and other waste will not be permitted.

19. Existing pollutant discharges in combination with abstractions may have an adverse effect on the water quality in the depleted reach.

20. Reduction in the hydraulic residence time may lead to algae growth in the depleted reach. If this is likely, the licensed volume will need to be reduced to protect the ecological requirements under the WFD.

21. Solids discharges will need to be prevented. Compliance with Suspended Solids Standards according to EU Freshwater Fisheries Directive and WFD “no deterioration” objectives will need to be tested.

22. The results of the chemical and biological assessment of many UK rivers and reaches are published on the Environment Agency’s website. Contact with the area office may provide further information. If no data are available, a survey may need to be carried out according to the Environment Agency’s monitoring procedures.

23. Water quality could deteriorate in the depleted reach due to flow depletion. Mass balance calculations may need to be carried out to check if this impact will be significant.

tick box		D Biological Water Quality Checklist	Note No.
YES	NO		
☐	☐	Has a biological status been identified for the affected reach?	24
☐	☐	Are planned changes in river flow likely to cause a significant change in the invertebrate community?	25
☐	☐	Does the Environment Agency hold aquatic vegetation survey data for the affected reach or for a nearby similar reach?	26
☐	☐	Are planned changes in the river flow likely to cause a significant change in the macrophyte, and diatom communities?	26

All green boxes ticked require no further action.

Any red boxes ticked require further action, as outlined in the attached notes.

Notes:

24. The results of the chemical and biological assessment of many UK rivers and reaches are published on the Environment Agency's website. Contact with the area office may provide further information. If no data are available, a survey may need to be carried out according to the Environment Agency's monitoring procedures. Species level aquatic macro-invertebrate data are usually necessary in order that an adequate appraisal of the resident community may take place. See checklist B Conservation.

25. The biology of the depleted reach needs to be investigated in detail. Sites with a higher biological score will be more sensitive to changes in river flow than sites with a lower score. An acceptable minimum flow can be determined following the guidelines in this guidance.

26. If representative survey data of these ecological elements are not available, they should be obtained, to determine that no deterioration or prevention of good ecological status will occur from the scheme. The impact of proposed changes in water level/velocity/submersion on the aquatic plant community may be derived from plant sensitivity studies.

tick box YES	tick box NO	E Fisheries Checklist	Note No.
☐	☐	Does the Environment Agency hold data on the fish species present in the affected reach?	
☐	☐	Does the river support migratory salmonids?	27
☐	☐	Does the river support lamprey species, shad species, or eels?	27
☐	☐	Does the river support coarse fish or non-migratory salmonids?	27
☐	☐	Is there an existing upstream fish pass?	27
☐	☐	Are the provisions for upstream fish passage satisfactory?	28
☐	☐	Are the provisions for screening fish and associated bywash satisfactory?	28
☐	☐	Will the scheme impact on either the up or downstream passage of fish in the river?	28
☐	☐	Will the scheme impact on any fish spawning or nursery areas?	
☐	☐	Will the scheme affect any river stretch used for angling?	

All green boxes ticked require no further action.

Any red boxes ticked require further action, as outlined in the attached notes.

Notes:

27. Where Atlantic salmon (*Salmo salar*) and migratory (sea) trout (*Salmo trutta*) are present, or where it is an objective to rehabilitate them to the river, then normally an upstream fish pass will be required. (Salmon and Freshwater Fisheries Act of 1975, Sections 9). Screening (SAFFA, S14) is required to be put in place unless exempted by the Environment Agency. The Environment Agency may reserve the right to ask for future provision of a fish pass around the structure.

    (*) To meet the requirements of the WFD it is necessary to consider passage not only for other major migratory species such as lamprey, eels and shad, but also for brown trout, grayling and coarse fish.

    (*) Some species e.g. lampreys, shad, bullhead are subject to particular protection by the European Habitats Directive.

    (*) As a result of the European eel stock being below its conservation limit, it is the subject of a European management plan requiring specific improvements to obstructions to maximise their migration. Eels are particularly vulnerable on their downstream migration and hence adequate screens are required in all places.

    Conservation legislation and regulations could change after these guidelines have been published. Therefore, up-to-date regulations should be consulted whenever necessary.

    Where Salmon Action Plans, Fisheries Action Plans or Eel Management Plans are available, they should be considered in relation to a hydropower proposal.

28. Fish passage and screening requirements are dealt with in section 4. The effectiveness and efficiency of any existing fish pass will need to be maintained or even improved for a scheme to be consented.

tick box YES	tick box NO	F Flood Risk Management Checklist	Note No.
☐	☐	Will the proposed scheme reduce the flood flow capacity of the river, either by reducing the cross section or by slowing flows?	29
☐	☐	Does the scheme propose any alterations to structures or construction of new structures in the river (such as weirs, dams, culverts or outfalls) or alterations to existing flood defences (such as embankments or walls)?	29
☐	☐	Does the scheme propose to create new channels or change the flow path in any way?	29
☐	☐	Does the scheme propose to deepen any existing channels?	29
☐	☐	Is the scheme in the floodplain as shown on the Environment Agency's flood map? Does the scheme reduce the available floodplain area or block potential overland flood flow?	29 & 29a
☐	☐	Will the scheme change the available access to the river or adjacent flood defences for maintenance, including by construction of fences or walls around new structures, or of overhead cables?	29b
☐	☐	Does the scheme involve construction of a new raised reservoir with the capacity of 25,000 cubic metres or more?	29c
☐	☐	Could the cumulative impact of the current proposal along with others increase flood risk or adversely affect land drainage?	29

All green boxes ticked – a flood defence consent application may still be required supported by sufficient information.

Any red boxes ticked require further action, as outlined in the attached notes.

Notes:

29. Formal written consent ('flood defence consent') from the Environment Agency is likely to be required for these activities. To ensure there is no adverse impact on flooding in the locality, a flood risk assessment is likely to be required to demonstrate that the effects of the proposal can be managed satisfactorily. Some construction activities may also require planning permission, and the views of the local planning authority should be obtained. The Environment Agency booklet 'Living On The Edge' (available free from our customer contact centre, or by download from http://www.environment-agency.gov.uk/homeandleisure/floods/31626.aspx) gives more information

29a http://www.environment-agency.gov.uk/homeandleisure/floods/31656.aspx

29b Operating authorities, including the Environment Agency on statutory main rivers, Internal Drainage Boards and local authorities elsewhere, have permissive powers to maintain watercourses to reduce flood risk. This is particularly important at river control structures, which may require operation, clearance of debris or repair. Vehicular access to these structures and ability to work safely around them needs to be retained, to ensure that this work can be carried out.

29c Structures of this size will qualify as statutory reservoirs, and require design and inspection as such. See http://www.environment-agency.gov.uk/business/sectors/32427.aspx for more details.

YES	NO	G Navigation Checklist	Note
☐	☐	Is the proposed scheme in a Navigation Authority controlled area?	30
☐	☐	Will the scheme reduce water levels upstream or downstream of the structure?	30
☐	☐	Will the scheme affect access for other users, e.g. canoeists?	30
☐	☐	Will the scheme affect water availability for navigation (lockage's) during low flows?	30

All green boxes ticked require no further action

All red boxes ticked require further action, as outlined in the attached notes

Notes:

30. Water levels may fluctuate as the turbine(s) are switched on or off. The local Navigation Authority must be consulted at the earliest stage. Formal permission for the works may be required where this has the potential to impact on navigation in the watercourse.

3. HYDROPOWER SITE LAYOUT

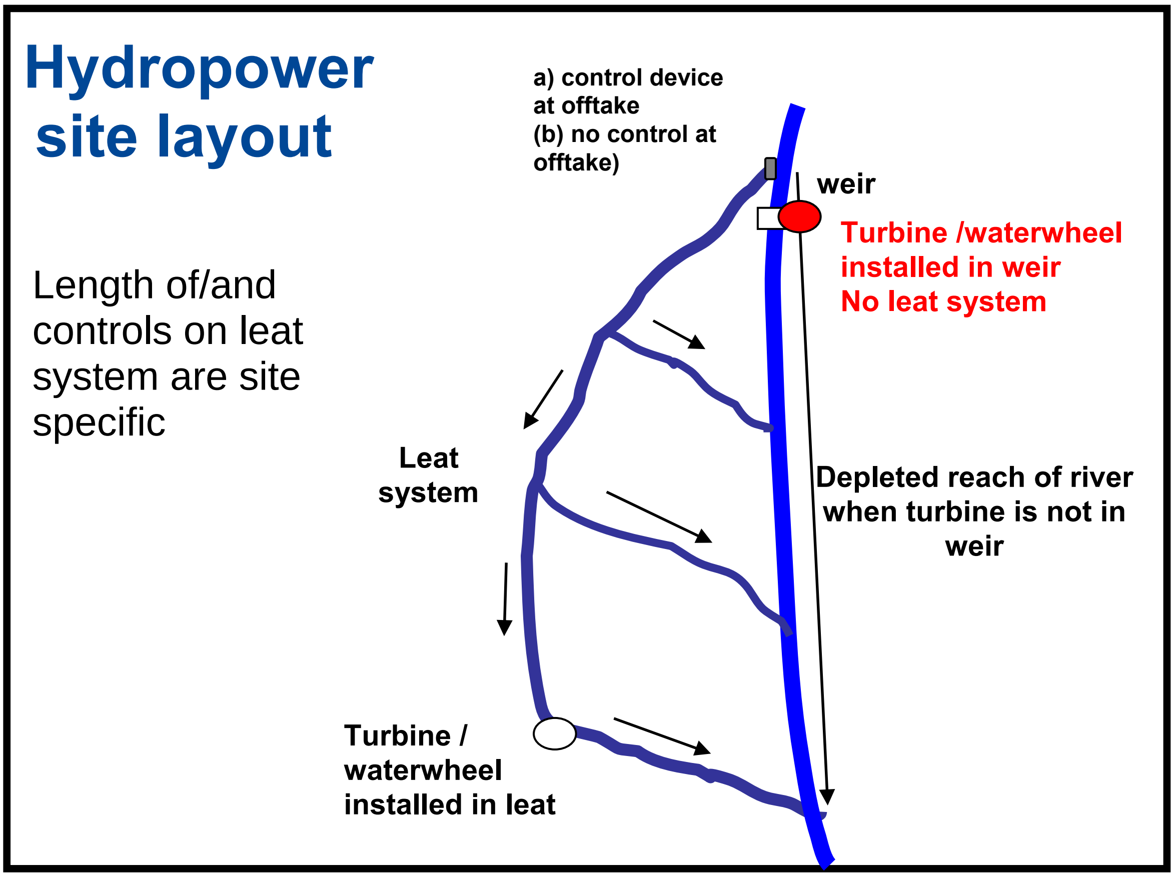

Figure 1 Typical hydropower site layout

Hydropower site layouts vary, but many of the main elements are shown Figure 1.

A weir (impoundment) is present in almost all hydropower sites, and may provide the head drop of water on its own, or in conjunction with a fall in the river over a greater length.

A leat system will divert water from the main channel to some point where the fall in water is used to generate power (often an old water powered mill). The leat system may have overflows to control the flow of water in the system.

The hydropower 'turbine' may be installed within or adjacent to the weir, or may be on the leat system.

A depleted reach occurs where water is diverted from the main channel through a leat system. Where the hydropower turbine is on the weir, the diverted reach is the weir itself. The impact of the hydropower proposals on flow and ecology in the depleted reach is one of the key issues in permitting Hydropower schemes.

The total flow in the stream above the intake and below the return will normally be unchanged (unless there are tributaries joining the depleted reach).

4. ECOLOGICAL REQUIREMENTS

4.1 Introduction

This guidance is intended to ensure sufficient water remains in the river. There is evidence that significant reductions in flows to watercourses lead to an impact on the ecology of that reach. As part of the WFD requirements, the Environment Agency through its regulation must aim to achieve good ecological status and ensure that there is no deterioration in the ecological condition of water bodies. It may be difficult to reconcile these requirements with a large loss of flow from main river channels. We are also obliged to consider the rights of land and fishery owners that may be affected.

Our evaluations indicate that hydropower schemes incorporated within or immediately adjacent to a main channel weir and which would avoid depleting main channel flows, are more likely to be environmentally acceptable.

4.2. Depleted Reach

A “depleted reach” may be an obvious length of watercourse, or it may be a weirpool when the turbine is situated on, or immediately adjacent to, an impoundment (see section 3).

Many old mill sites were built with either a moderate length of intake channel, a tailrace channel, or both (often partly culverted). This helped isolate the millhouse from flood flows and preserve the driving head during high flow conditions (when the weir itself might be drowned out). Many of these mill races still exist and provide the majority of current opportunities for low head projects.

Because of the cost of excavating new waterways, it is rare for a 'green-field' low-head scheme to involve more than a few tens of metres of new channel, so the depleted reach may be very short.

Where water is diverted from the main river, the length of channel from the diversion point to its re-connection will have a depleted flow with a consequential impact on its ecological and fishery status. If this is a migration route and the diversion channel has the majority of the flow, then the fish may be attracted to the higher flows. If the migratory fish enter the tailrace this may prevent migration (if there is no fish pass in the diversion channel), or delay migration possibly resulting in increased predation, disease or inability to reach the destination at the right time. Equally, downstream migrants may tend to migrate into the diversion channel with greater risk of impingement on screens and turbines. For these reasons the Environment Agency recommends avoiding such schemes as it recognises there will generally be less environmental risks for ‘on weir’ schemes and therefore possibly greater power production potential. This avoids causing a depleted reach and the flows can be held to one channel and so minimise fish migration problems and the associated costs for developers.

There is increasing understanding that depleted reaches need to retain a flow regime that mimics the natural flow fluctuations, and that all elements are important including floods, medium and low flows. A depleted reach, caused by a hydropower offtake, will be deprived of a varying proportion of the natural flow that has a complex relationship with the river type (high or low baseflow) and the maximum hydropower volume in relation to the Qmean flow of the river (see section 6). The ecological impact this may have will depend on the river’s ecological status, the length of the depleted reach, and could vary from being acceptable to being quite damaging.

To maintain the ecological integrity of the river, minimum flows in the depleted reach will need to be set and factors such as flow variability and spate flows will become more important for both maintenance of channel form and its ecology as the length of the depleted

reach becomes longer. The quality of the fishery and its significance for fish passage are also likely to be affected. On shallow 'pool and riffle' type rivers there can be significant change in the 'wetted usable area' at low flows, especially below Q95 (the flow exceeded for 95% of the time, and used as a marker of low flow). Q95 is therefore the default 'Hands Off Flow' for licensing consumptive abstractions, see Environment Agency – Managing Water Abstraction.
http://publications.environment-agency.gov.uk/pdf/GEH00508BOAH-E-E.pdf

Increased periods of low flow in the depleted reach will result from a hydropower proposal, and may have significant impacts on fish populations – both in coarse fish dominated rivers and salmonid rivers. There has been little scientific study on this undertaken in England and Wales, but evidence from Europe and elsewhere indicates a considerable reduction in biomass and density of both coarse and salmonid species in the depleted stretch when subjected to lengthy periods of very low residual flows.

If an impoundment has no fish pass but fish are able to pass either at high flows or a flow "window", any diversion of water through a turbine will impact on the migration capacity. Therefore it is unlikely that a project would be allowed unless it included a suitable fish pass.

Weir pools are important habitats in some lowland rivers and, although the volume of water above and below the weir may be the same when the hydropower generation is 'on weir', the change in flow distribution and energy may have effects on the morphological character of the river. There will be different requirements depending whether the hydropower turbine is situated on or adjacent to the impoundment, or is on a channel (or leat) away from the main channel, and whether there are fish migration requirements (this is developed in the scenarios in section 5).

4.3. Salmon and Freshwater Fisheries Act (SFFA) and migratory rivers

Hydropower installations on rivers populated by migrating species of fish, such as salmon or sea trout, are subject to special requirements as defined in the Salmon and Freshwater Fisheries Act (SFFA). Broadly, and subject to certain conditions, the Act requires that "*owners/operators of hydropower schemes on migratory rivers should, at their own expense, ensure that upstream and downstream fish passages, respectively, are catered for by the construction of appropriate fish passes, screens and by-washes*".

In the context of licensing of abstracted flows, the key issues for migratory species are as follows:

- The need for fish passes to overcome the increased obstruction posed to upstream migration by weirs and other river structures that are deprived of flow.
- Where there is no fish pass, adequate residual flow over the weir during the migration seasons for adults (moving upstream) and juveniles (moving downstream).
- Adequate flow in the depleted reach during the migration seasons for adults (moving upstream) and juveniles (moving downstream).
- Protection of spawning areas and the seasonal flows required to allow spawning to occur.

A fish pass will be required on hydropower sites on rivers where there are migratory species if the ability to migrate is compromised. The residual flow calculation will need to include the flow required to service the fish pass.

The requirement for fish passes and screening is likely to extend to all species in the near future to meet the objectives of WFD. These changes will be made through amendment to fisheries legislation. Consultation on the proposals took place in spring 2009. Developers are advised to make themselves aware of the possible implications.

Further consideration of fish passes is in section 8.

4.4. Seasonal fish migration

Different fish species migrate upstream (particularly for spawning) and downstream for spawning, feeding and over-wintering, at different times of the year. The flow requirements for the different species vary significantly.

- Adult salmon and sea trout will generally migrate upstream from May to January to access spawning areas. Upstream migration is triggered by flow spates that will normally exceed Qmean flows. After spawning, adults move downstream through main flow routes in December to February.
- Smolts (juvenile salmon and sea trout) migrate downstream mainly in the spring, prompted by temperatures in excess of 9-10°C. There is evidence of a second migration period in autumn in some rivers.
- Trout will move upstream to spawn from October to February dependent on a range of factors.
- Coarse fish will generally seek to migrate to spawn during March to July, depending on the species.
- Lamprey adults migrate upstream to spawn (sea lamprey, February to June; river lamprey, September – March). Juveniles migrate downstream to feed (sea lamprey, October to December; river lamprey January to April).
- Eels make their main downstream migration mostly during autumn (September to November). Peak migrations will occur over short periods that may be predictable in relation to moon phase, water temperature and high flows.
- Elvers make their upstream migration during March to May depending on location. They may require only relatively low cost solutions to enable them to pass weirs and other impoundments successfully.

All these periods are approximations and vary according to the geographic location and in some case specific strain of fish present. Local confirmation of these will be available from Fisheries consenting teams.

4.5. Hydropower and WFD

Under the WFD Member States should aim to achieve good ecological status and to ensure that no deterioration of ecological status takes place. The freedom of movement of fish, upstream or downstream, is an important component of achieving or maintaining good status or potential. Hydropower schemes must be well designed and carefully sited if they are to avoid disruption of fish migration in both upstream and downstream directions, and thereby create an obstacle to achieving WFD Good Ecological Status. The ecological and amenity impacts in any depleted reach must be considered, both to the reach itself and to the catchment as a whole.

Rivers with low head hydropower structures are not necessarily designated under WFD as Heavily Modified Water Bodies by hydropower use, as the impacts are on a relatively short length of the river compared to the length within the water body.

The UK Technical Advisory Group (UKTAG) recommendations on flow standards for abstraction impacts (WFD 48) are for consumptive abstraction impact. They have been adopted by the Environment Agency in a slightly modified form for water resource regulatory purposes as ‘Environmental Flow Indicators’, and will be used in the Future Catchment Abstraction Management Strategies (CAMS) process for managing abstraction licences.

UK TAG guidance has also been provided on the assessment of abstraction impacts greater than those indicated in the WFD 48 project on short lengths of river within a water body but which would not be considered sufficient to cause a failure to support Good

Ecological Status. The proposals presented here for considering the length of the depleted reach when assessing hydropower proposals meet the requirements of the UK TAG guidance.

Barriers to fish passage have been highlighted in WFD River Basin Planning as a major impact limiting fish populations, particularly of salmon and trout but also of coarse fish and eels. Improvements in water quality on many rivers in industrial areas have enabled the slow return of salmon and other fish species to rivers that lost their populations due to major weir construction for water use, and later, pollution from industrial processes. There are many thousands of such barriers in England and Wales. The Environment Agency is undertaking work to collate data on barriers, prioritise work to enable fish passage (by removal of the barrier or installation of a fish pass), and to obtain powers and funding to enable such work. The development of hydropower involving a weir that is a barrier to migration would lead to the need to install a fish pass.

4.6 Hydropower and Protected Areas

Where a hydropower proposal has been identified through the Conservation checklist as being likely to have an impact on a designated site (SAC, SPA, SSSI etc) further work will be required to assess the impact of the scheme on designated species.

Consultation with Natural England or Countryside Council for Wales (CCW) will be required in assessing the impacts of the scheme and granting permits.

4.7 Cumulative Impacts

In regulating low-head hydro applications, the Environment Agency will take in to account potential cumulative impact of multiple sites on a river or in a catchment. Without effective fishery protection measures, cumulative impacts may be significant, particularly for diadromous species such as salmon, sea trout, lamprey, shad and eel. They may also be significant for other solely freshwater species that are obliged to migrate between habitats as part of their life cycle. Some rivers are potentially suitable for multiple sites for low-head hydropower applications. A high level of fishery protection needs to be maintained at such sites; even where sites have efficient and effective downstream and upstream passage facilities, the cumulative effects of delays and damage may cause the numbers of migrating fish to decline significantly but there has been no research carried out to provide evidence to show that this actually is happening.

The location of a proposed scheme within a catchment will also be relevant in terms of the environmental protection required. Risks for diadromous fish in particular will generally be higher the lower down the system the site is located. This is because the potential impacts in terms of the number of migrants and proportion of the population affected will be at the maximum for both upstream and downstream moving fish in the lower reaches of a river basin.

5. HYDROPOWER SCENARIOS

Hydropower sites fall in four main scenarios

1. Turbine on or immediately adjacent to an impoundment (weir) – with no fish migration issues.
2. Turbine on or immediately adjacent to an impoundment (weir) – with fish migration issues.
3. Mill leat used for hydropower abstraction – no fish migration issues.
4. Mill leat used for hydropower abstraction – fish migration issues.

5.1. Turbine on or immediately adjacent to an impoundment (weir) – with no fish migration issues

Situation:

- Where an impounding structure (weir) on the river is to have a turbine installed within its longitudinal footprint to return water at the impoundment toe.
- It is not a migratory salmonid river, or there is no Salmon Action Plan.
- Fish, which are interest features of protected sites including the river reaches above and below the weir, are achieving favourable conservation status.
- The river reaches above and below the weir are not failing Good Ecological Status due to obstructions to fish passage, of which this is one of the relevant sites.

Requirements:

- The maximum flow for hydropower will normally be Qmean (Table 2).
- The Hands-Off Flow value for that river type is preserved (Table 2).
- The turbine intake will have the screening arrangements specified in Figure 5, including a bywash.
- The water is returned in the same longitudinal direction of the flow to maintain weirpool form.
- The weir has a required minimum depth of water flowing over it while generation is taking place, taking into account factors such as design of the weir, amenity and whether the river has a high baseflow.
- There are no other parties dependent on or adversely affected by the re-distribution of flows at the structure or the reduced kinetic energy of the flow into the weirpool.
- Where the weir pool is assessed to have high ecological importance – for example on a heavily impounded lowland river, a flow regime may be required to support its continued presence.

5.2 Turbine on or immediately adjacent to an impoundment (weir) – with fish migration issues

Situation:

- Where an impounding structure (weir) on the river is to have a turbine installed within its longitudinal footprint to return water at the impoundment toe.
- It is a migratory salmonid river, or there is a Salmon Action Plan.
- The river has other fish species which need to migrate past the weir to successfully complete their life cycle.
- The river has coarse fish for which it is failing Good Ecological Status due to migration obstructions or impoundment impacts of which this is one of the relevant sites.

Requirements :

- The maximum flow for hydropower will normally be Qmean (Table 2).

- The Hands-Off Flow value for that river type is preserved (Table 2).
- The turbine intake will have the screening arrangements specified in Figure 5, including a bywash, to ensure safe downstream passage of migratory fish.
- The water is returned in the same longitudinal direction of the flow to maintain weirpool form.
- The weir has the required minimum depth of water flowing over it when generation is taking place, taking into account factors such as design of the weir, amenity and whether the river has a high baseflow.
- A fish pass will be required to a design approved by the Environment Agency.
- The fish pass and turbine outflow shall be co-located to ensure fish are preferentially drawn to the fish pass entrance and to ascending it throughout the flow ranges experienced at the site.
- There are no other parties dependent on or adversely affected by the re-distribution of flows at the structure or the reduced kinetic energy of the flow into the weirpool.
- That where fish survey data to classify for WFD above and below the site are not available, that these will need to be provided by the developer to enable assessment against Good Ecological Status (GES) to be made by the Environment Agency.
- Where the weir pool is assessed to have high ecological importance – for example on a heavily impounded lowland river, a flow regime may be required to support it.

Weir pools

- There are a few sites of high ecological value that have been identified by the Environment Agency where weirpool constraints will limit hydropower potential.
- Weirpools are important for spawning and fry development of several riverine fish species, such as barbel, dace, chub, bullhead, stone loach, and as a habitat for macrophytes and invertebrates. These may contribute to the fishery and wider ecology for a distance downstream and therefore affect both WFD achievement of GES and the fishery rights of others.
- The essential habitat for these species is formed and maintained by the energetic water entering the weirpool.
- Whilst flood flows may create the appropriate morphology, moderate flows will maintain it in a suitable condition.
- A turbine situated on, or immediately, adjacent to the weir may discharge water into the weirpool, but the flow pattern and energy will have been changed.

5.3. Mill leat used for hydropower abstraction – no fish migration issues

Situation:

- Abstraction for hydropower through the mill leat creates a depleted reach greater than the longitudinal section of the weir.
- It is not a migratory salmonid river, there is no Salmon Action Plan.
- Fish which are interest features of protected sites including the river reaches above and below the weir are not failing to achieve favourable conservation status.
- The river reaches above and below the weir are meeting GES due to fish migration obstructions or impoundments of which this is one of the relevant sites.

Requirements :

- The maximum flow for hydropower will depend on the river type (Table 2).
- The Hands-Off Flow value for that river type is preserved (Table 2).

- The turbine intake will have the screening arrangements specified in Figure 5, including a bywash.
- The weir has the required minimum depth of water flowing over it when generation is taking place, taking into account factors such as design of the weir, amenity and whether the river has a high baseflow.
- There are no other parties dependent on or adversely affected by the re-distribution of flows at the structure or the reduced kinetic energy of the flow into the weirpool.

5.4. Mill leat used for hydropower abstraction – fish migration issues

Situation:

- Abstraction for hydropower through the mill leat creates a depleted reach greater than the longitudinal section of the weir.
- It is a migratory salmonid river, or there is a Salmon Action Plan.
- The river has other migratory fish species.
- The river has coarse fish for which it is failing GES due to migration obstructions or impoundment impacts of which this is one of the relevant sites.

As a development of Scenario 3, the difference this causes is that a fish pass is required and that the flow distribution between the leat and the depleted reach, and attraction flows for migratory fish are arranged to ensure fish migration through the overall site is readily achieved by all relevant species. This will specifically require the upstream route to be preferentially found and utilised even in high flows. For downward migrants, screening and by-wash arrangements must enable un-delayed and safe passage downstream.

Requirements :

- The maximum flow for hydropower will normally depend on the river type (Table 2).
- The Hands-Off flow value for that river type is preserved (Table 2).
- The turbine intake will have the screening arrangements specified in Figure 5, including a bywash.
- The fish pass and channels leading to it should be adequate for the relevant species to ensure their easy passage through the site.
- Under most flow conditions, including high flows, the majority of the flow and velocity will be sustained in the route and channel to the fish pass to ensure high attraction towards it.
- Flow distribution between the mill leat and the depleted reach, so as to ensure high attraction to the fish pass route will require careful design, and may require a reduction in the maximum hydropower flow below Qmean and/or a large Hands-Off Flow.
- Suitable arrangements should be made to prevent migratory fish from entering the tailrace from the turbine where this is not the fish pass route, and that these arrangements do not interfere with any downstream movement of fish through the tailrace.
- Where fish survey data to classify for WFD above and below the site are not available, these will need to be provided by the developer to enable assessment against GES to be made by the Environment Agency.

6. PERMITTING

The permitting of hydropower schemes is not always straightforward, because of:

- The site-specific nature of individual site layouts.
- The fisheries and environmental needs of the watercourse.
- The requirement for a number of different 'approvals' contained within the water resources permit.
- The requirement for flood defence consent .
- The contentious nature of some hydropower schemes.

Early discussion with affected parties may help to resolve some of the concerns.

6.1. Water Resources permits

Where an abstraction is within the banks of the watercourse, it is currently considered not to require an abstraction licence. This situation may apply to weirs that contain the generating equipment within the weir. An impoundment licence will be required if changes are made to the weir. This covers

(a) a barrage-type project where turbines are installed on an existing weir and the water remains between the existing banks of the river.
(b) a new scheme installed in the workings of an old mill site where the mill leat has been adopted as 'main river'.

The Water Act 2003 amended the Water Resources Act 1991 to provide for three types of abstraction licences; Transfer, Temporary, Full Licences. All abstraction licences must be Time Limited – this will normally be 12 years, but will be to the Common End Date for the catchment, as set out in Catchment Abstraction Management (CAMS) documents.

- **Transfer Licence -** where water is transferred from one 'source of supply' to another without intervening use**.** Hydropower schemes will normally be permitted using a Transfer Licence to authorise the removal of water from the main watercourse through a 'leat' or similar and returning the water to the main watercourse. There is no annual abstraction charge on a transfer licence.

- **Temporary Licence –** authorises abstraction for a maximum of 28 days. Not applicable to hydropower.

- **Full Licence –** authorises abstraction for a 'use' and is chargeable under the Environment Agency abstraction charging scheme. There is still an exemption from charges for hydropower under 5Mw, but Full Licences will not normally be used for hydropower schemes. Full licences will not be granted on hydropower schemes without the applicant agreeing to a derogation condition that enables the Environment Agency to grant abstraction licences upstream of the hydropower site in accordance with its CAMS policy.

Impoundment Licence - applies if changes are being made to structures which impound water, such as weirs and sluices, or if new structures are to be built.

The Environment Agency may also require a **Section 158 Agreement** to be drawn up, which defines certain further details on the way the scheme must be operated in order not to conflict with the Environment Agency's river management duties, e.g. rights of access, the control of river levels, maintenance of the weir and river structures, fisheries and other environmental protection duties, etc.

6.2. Salmon and Freshwater Fisheries Act and further regulations for WFD (see note)

The requirements for fish passes and fish screens will normally be conditions on the abstraction licence.

- **Fish Pass approval** - authorises the form and operating requirements where a fish pass is required or altered for the scheme proposed.
- **Fish screen regulations** - will require a fish screen or an exemption to be issued by the Environment Agency for new or altered intakes and discharges.

Note: Defra are implementing regulations in 2009 to broaden these to all waters and species.

The requirements of the Salmon and Freshwater Fisheries Act will normally be covered by conditions on the Water Resources permit and/or the Flood Defence/Land Drainage Consent, after internal consultation within the Environment Agency. These may affect the amount of water available and constraints of any scheme.

6.3. Flood Defence

The consent of the Environment Agency is required for:

- any works being carried out within, over or under the channel of a statutory 'main river', including its banks, including alteration of existing structures (Section 109 Water Resources Act 1991).
- erection of culverts or flow control structures within any watercourse, or alterations to these that will affect flow, where this is not in an Internal Drainage Board operating area (Section 23 Land Drainage Act 1991). In 2009 Defra and the Welsh Assembly Government are consulting on the draft Floods & Water Management Bill on transferring this duty, and responsibility is likely to change in future.
- erection of structures including buildings, walls and fences etc, within the 'byelaw margin' of a main river (Environment Agency Regional Land Drainage / Flood Defence Byelaws). This margin is specified in byelaws, which vary around the country. Developers should consult the local Environment Agency office over proposals for any structures within 20m of a main river, to ensure this requirement is assessed, though consent will not be required for every case.

Pre application discussions are encouraged, to confirm what formal consents may be required, and to ensure that appropriate works are designed. The Environment Agency booklet 'Living On The Edge' (available free from our customer contact centre, or by download from http://www.environment-agency.gov.uk/homeandleisure/floods/31626.aspx) gives more information.

6.4 Other permissions

This section is not definitive and applicants will need to ensure they have met the requirements of any relevant authority.

Erection of culverts, flow control structures, or alterations to these that will affect flow, within any Internal Drainage Board managed watercourse is likely to require consent from the Board concerned (Section 23 Land Drainage Act 1991). Internal Drainage Boards within their districts, or local authorities elsewhere, may have local byelaws relating to flood defence and land drainage on ‘ordinary watercourses’ (those that aren’t defined as main rivers). Developers should make enquiries locally as to whether any elements of a proposal are affected by these.

Planning permission may be required from the local planning authority for ‘engineering operations’ (consult the relevant local authority for their interpretation of this requirement). Many weirs and mills are considered as ‘Heritage sites’ which may require permission for works.

7. ABSTRACTED FLOW REGIME AND FLOW IN THE DEPLETED REACH

As noted in section 4, the Environment Agency will look more favourably on schemes that do not lead to a depleted reach.

The flow regimes proposed in this guidance set out a default position that is considered acceptable for hydropower generation without having an unacceptable environmental impact. Whilst we will consider variances from this guidance, these must be fully justified, for example:

- If the environmental audit has identified an important environmental impact, the acceptable flow regime may require more detailed assessment, which may limit the water available for the hydropower scheme. For example, an impoundment where migration is possible at higher flows, or where there is a diadromous fish spawning site.
- Hydropower proposals on a river that splits into more than one channel may require more careful consideration of the flow characteristics in each channel in order to determine an appropriate residual flow.

The hydrological design and regulation of hydropower schemes involves a number of inter-related factors, including:

- Flow for hydropower
- Flow in the depleted reach
- Length and ecological value of the depleted reach
- The baseflow characteristics of the river and/or its 'flashiness'
- The minimum depth of water passing over the weir crest, and whether a fish pass is present
- Nature of the ecology, including fish populations, especially in relation to flow sensitive communities, salmonid fish and other species which have to migrate to complete their life cycle such as lamprey, shad, & eel, as well as potamodromous (migrating within the river) species
- The rights of owners, fishery interests and other uses that may be affected

The combination of these factors will determine whether a scheme is environmentally acceptable and will vary with each site. Default conditions are set out which are intended to safeguard the ecology of the majority of sites whilst allowing generating capacity.

Information about a number of hydrological parameters is essential for the design of an environmentally acceptable scheme. These are set out below.

7.1. Hydrological Parameters

- Annual Hydrograph
- Flow Duration Curve
- Mean Flow (Q_{mean})
- Base Flow Index and the Ratio of Q_{95} to Q_{mean}
- Residual Flow (Q_R) – the flow in the depleted reach
- Hands-Off Flow – a flow specified in the abstraction licence below which abstraction must stop.
- Design Flow (Q_o)
- Turbine start-up flow.

7.2. Annual Hydrograph

There are two ways of expressing the variation in river flow over the year: the Annual Hydrograph and the Flow Duration Curve (FDC).

An annual hydrograph, as depicted in Figure 2, simply shows the day-by-day variation in flow over a specific time period (calendar year in Figure 2).

There is general recognition that ecologically important features of a hydrograph are:

a) 'flow variability'
b) natural low flows and the flow recession curve
c) 'peak' flows sufficient for channel shaping and cleaning of substrata.

Hydropower schemes generally have most impact on mid-range river flows, and a Hands-Off Flow or Level protects low flows.

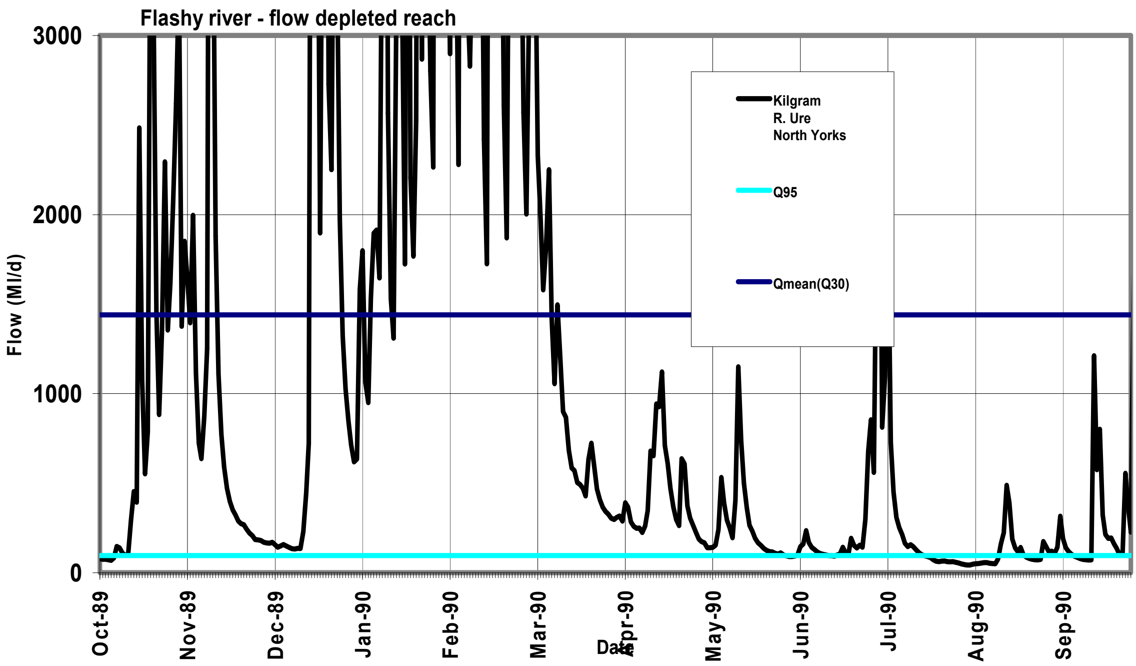

Figure 2 Hydrograph – daily flows

A flashy river – peak flows are in excess of 10000Ml/d

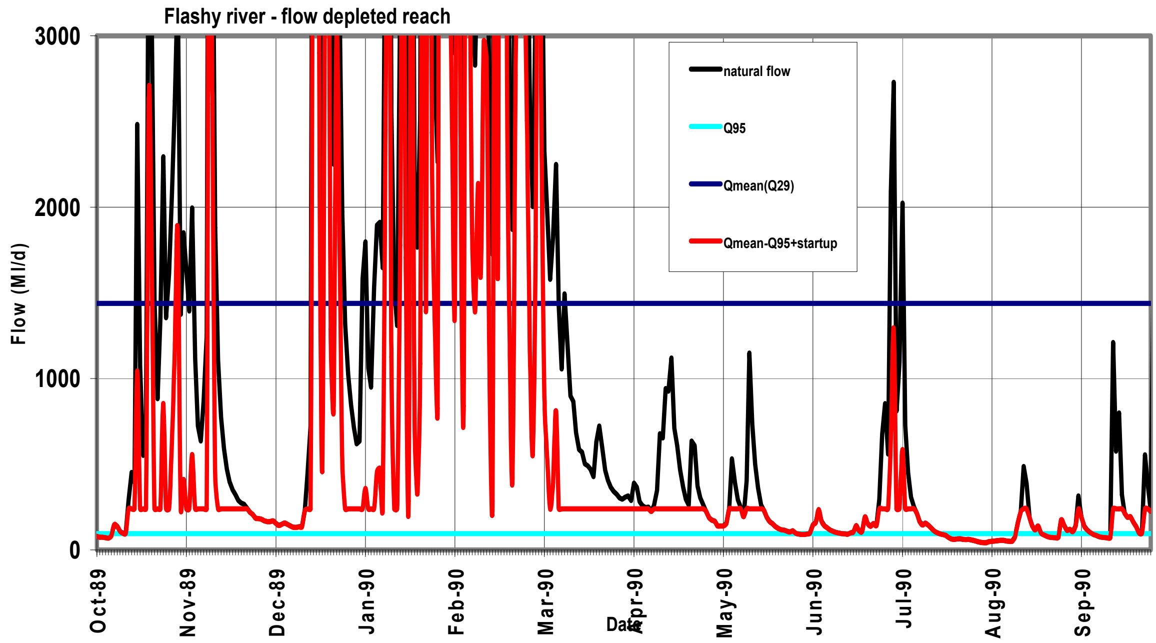

Figure 3 Hydrograph – showing impact of hydropower on flow in depleted reach (red line) –

based on maximum turbine flow of Qmean, and Q95 Hands-Off Flow

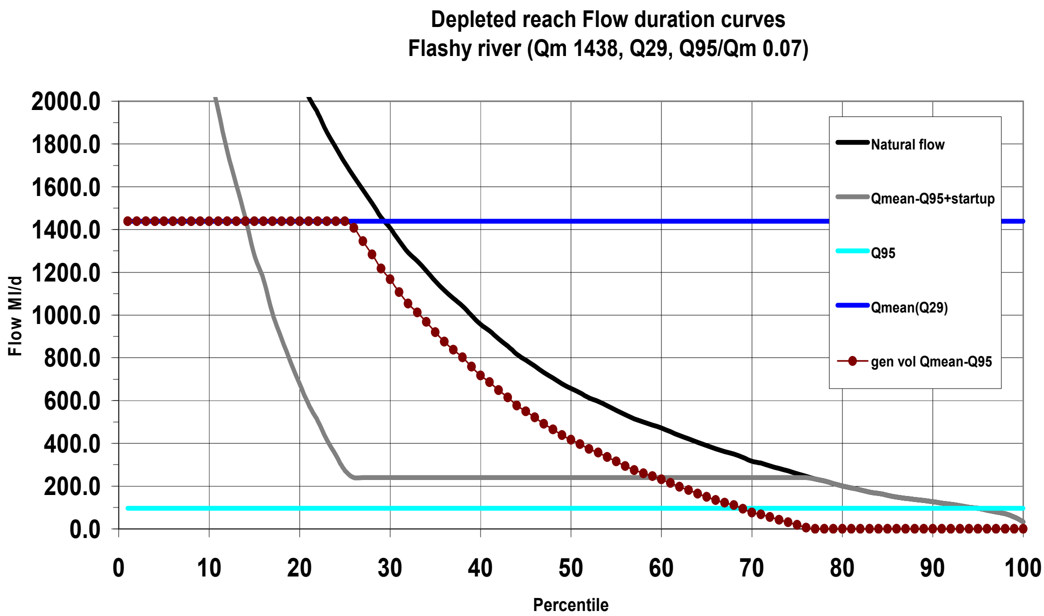

Figure 4 Flow Duration Curve – for same river as hydrographs

7.3. Flow Duration Curve

The Flow Duration Curve (FDC) presents the statistical availability of any given flow, based on best available data. An example is shown in Figure 4. The vertical axis gives the flow rate, the horizontal axis gives the percentage of time that the flow is exceeded.

The FDC can immediately indicate the volume of flow which will be available for any percentage of time, for example the flow exceeded for at least 50% of the time is known as Q_{50} - the median flow. Q_{95} is a frequently used parameter because it is taken as the characteristic value for the natural low flow in the river.

The FDC is more relevant than the hydrograph when calculating the flow available for a hydro-power scheme. It enables the potential flows for hydropower to be assessed, and in turn the average energy output and revenue of the scheme, as well as enabling the assessment of the hydrological impact on flows in the depleted reach. The FDC is therefore the key tool for discussing abstracted and residual flow values.

The Environment Agency uses FDCs in its management of water resources and setting of 'Environmental Flow Indicators' in its Catchment Abstraction Strategies. Where a catchment has a gauging station it uses observed (measured) flows to derive the FDC.

On streams and rivers, where there may not be any gauged data for developing a Flow Duration Curve, the Low Flow 2000 hydraulic model developed by the Centre for Ecology and Hydrology can provide computed data for a FDC. The model examines rainfall data, catchment geology and gauged measurements from the nearest relevant gauging stations to model the flow characteristic at a given river location. This is the best available flow modelling tool for England and Wales.

Hydropower developers can also access this tool on a fee-paying basis by contacting the Centre for Ecology and Hydrology via www.hydrosolutions.co.uk/lowflows.

7.4. Mean Flow (Q_{mean})

As its name implies, the mean flow at a particular point in a river is the average of all flow measurements taken over a long period of time. Over a single year, the mean flow is the total volume of water delivered to the river from the catchment area in that year, divided by the number of seconds in a year. Relative to the Flow Duration Curve, Q_{mean} is typically in the range Q_{30} for very flashy upland rivers to Q_{40} on lowland and high baseflow rivers, meaning that flows are greater than this for 30% and 40% of the time respectively.

7.5. Depleted reach

The depleted reach is between the point where water is abstracted from the river and the point where it is returned (Figure 1 and section 3 and 4).

The length of the depleted reach may range from the upstream water level to the downstream water level over the face of the weir (where the generating equipment is incorporated into or adjacent to, the weir) to many hundreds of metres, where water is conducted along a pipeline or open channel (a 'leat' or 'mill race') to the generating plant and until the water rejoins the main channel. A very long depleted reach may sometimes gain flow from tributaries. Longer depleted reaches on flashy rivers (**Q_{95}:Q_{mean} ≤ 0.1**) may require a Hands-Off Flow in excess of Q95.

7.6. Hands-Off Flow or Level

For both environmental and aesthetic reasons, a certain minimum flow needs to be reserved to continue over the weir and down the depleted reach. The Agency will normally set a **Hands-Off Flow (HOF) or Level** as a condition on hydropower schemes, such that when the flow or level falls below the set value, abstraction must stop.

To ensure that the HOF is complied with, hydropower abstraction will be unable to start operating until the flow is above the HOF by a quantity that is at least equal to the 'turbine start up flow' (see section 6.9). In some cases generation may start or stop at flows considerably higher than the HOF (especially flashy rivers where **Q_{95}:Q_{mean} ≤ 0.1** and the maximum design flow is more than 10 times the HOF).

The residual flow in the river may therefore be greater than the HOF, and after generation has stopped may also naturally fall below the HOF. The amount of residual flow, and factors such as flow variability, may become more important as the length of the depleted reach increases, and it will often result in issues with fish migration.

7.7. Base Flow Index and the Ratio of Q_{95} to Q_{mean}

Base Flow Index (BFI) is a term developed by the Institute of Hydrology to describe how river flow regimes vary with geology. It is intended to provide a measure of how much the river flow is affected by stored sources, such as permeable rock, which enables the 'base flow' in the river to be sustained in dry conditions (high BFI value), unlike rivers derived from clay or hard rock catchment areas, which would have a low BFI value.

For practical purposes, the BFI is a parameter which describes how widely the flow on a particular river varies on a daily basis and between wet and dry seasons. A 'flashy' river with high winter peaks but low summer flows would have a low BFI because the typical low flow is a small proportion of the mean flow.

The calculation of BFI following the specific methodology of the Institute of Hydrology, uses information that may not be readily available for a specific site. Therefore an alternative approach is proposed which allows a simple and rapid categorisation of the base-flow nature of any UK river.

This approach utilises the two flow parameters most commonly used by the Environment Agency in connection with rivers and streams of any size, namely:

- Q_{mean} the mean flow
- Q_{95} the flow exceeded for 95% of the year; usually taken as the characteristic value for the natural low flow in the river.

The ratio between Q_{95} and Q_{mean} for a particular river provides a good estimate as to whether the BFI is high or low. Therefore, for the purposes of making a simple assessment of the baseflow characteristic for a river, the ratio Q_{95}:Q_{mean} will be used in these guidance notes.

For the purposes of dividing UK rivers into categories for high, medium or low base-flow characteristics, the following values are easy to use and appear to fit well with the mix of UK rivers:

Category	Range	Examples
Low baseflow	$Q_{95}:Q_{mean} \leq 0.1$	Tamar, Conwy, Ribble, Lune, Kent
Medium baseflow	$0.1 < Q_{95}:Q_{mean} < 0.2$	Thames, Severn, Wharfe, Dee
High baseflow	$Q_{95}:Q_{mean} \geq 0.2$	Trent, Aire, Wey

Table 1 River types using $Q_{95}:Q_{mean}$ ratios

High baseflow rivers include those with significant areas of major aquifers contributing to river flows, and also those with major urban areas providing large volumes of Wastewater Treatment Works (WWTW) effluent.

For both environmental and hydropower reasons it is important to distinguish the different types of rivers as indicated by the Q_{95}:Q_{mean} ratio. Acceptable hydro schemes where the hydro unit is 'on weir' may be very different hydrologically for a high baseflow river compared to a low baseflow (flashy) river.

Note: Where rivers are significantly impacted by abstraction (see CAMS results) it may be necessary to compare the gauged Q95 (Qg95) with the natural Q95 (Qn95). Qn values will be used in setting HOFs.

7.8. Maximum Design Flow (Q_o)

Typically a hydropower developer will choose a design flow for the scheme which allows it to use a good proportion of the higher flows, but also to continue to operate down to reasonably low flows so that output can be sustained for as much of the year as possible. Common practice has been to use Q_{mean} flow as the design flow.

From an environmental perspective, a high design flow reduces the flow variability in the deprived reach, particularly on flashy rivers. A maximum design flow greater than Q_{mean} is unlikely to be acceptable and may need to be less on very flashy rivers.

7.9. Turbine start-up flow

Two factors must be considered in the start/stop of a hydropower generating unit.

(a) a water turbine only achieves a worthwhile efficiency when it can pass a good proportion of its design flow, typically between 15% and 30% depending on machine type. The turbine will also shut down when the available flow falls below this minimum operating value or start up flow.

(b) the turbine control system needs to add an additional margin to be sure that the turbine will not shutdown as soon as it starts up, and then 'hunt' around the start-up condition, switching on and off.

To observe the HOF, the hydropower turbine will be unable to start generating until the flow exceeds the HOF by the start up flow and will need to stop generating when the flow in the river falls to the HOF + start-up flow. For compliance purposes, generation cannot take place when flows are below the HOF or Hands-Off Level at the point specified in the permit.

7.10. Flow "Pulsing"

With a well designed low-head scheme, flow pulsing (caused by drawing the water level below the crest level of the weir, and then stopping generation to allow the water level to pond up behind the weir) should never occur. The design and control system must ensure this cannot happen. The requirement to maintain a specified flow over the weir while generating, and a HOF at which generation must cease will prevent pulsing.

7.11. Matrix of Design Flow and Hands Off Flow

Table 2 presents a table of default minimum flows relating to river types using the Q_{95}:Q_{mean} ratios (Table1). The maximum flow that may be considered for hydropower is Qmean

Q95/Qmean Depleted reach	Flashy river <0.1 fish migration issues	Flashy river <0.1 NO fish migration issues	0.1 to 0.2	high baseflow >0.2
Weir Max HOF	Qmean Q95	Qmean Q95	Qmean Q95	Qmean Q95 BUT see NOTE
Up to 200m Max HOF	Q40 Q90	Qmean Q90	Qmean Q95	Qmean Q95
>200m Max HOF	Q40 Q85	Qmean Q85	Qmean Q90	Qmean Q95

Table 2 Maximum hydropower flows, Hands Off Flows according to river type (Q95:Qmean)

NOTE

On large high baseflow rivers where the turbine is ‘on weir’, and a fish pass is installed OR there are NO fish migration issue, it is possible to consider a residual flow over the weir that is set for amenity criteria (see sections 4 & 5).

The values in this table are intended for low head schemes. Further work is required on high head schemes especially where there are long depleted reaches.

8. FLOW MONITORING

8.1. Objective

Hydropower is largely a 'local impact' on the river system if the water is returned to the same watercourse. It is therefore control and monitoring of the local impact that is most important.

The Environment Agency will expect a control and monitoring system that ensures flow in the depleted reach is controlled and monitored and data recorded to demonstrate compliance with licence conditions. The method by which such flows or levels are measured and recorded is likely to differ in detail for each site, but should be provided by the developer.

Under the Water Resources Act 1991 the Environment Agency must specify on the abstraction licence the maximum volumes that may be abstracted, and also the Instantaneous, hourly and daily rates of abstraction. These can be calculated from the FDC and design parameters of the hydropower installation.

The maximum annual volumes will be set on the basis of 220 days of max. daily rate, as the maximum daily rate will not be available for 365 days. More detailed hydrological analysis should be made when assessing the potential of the scheme.

As the hydropower abstraction is normally non-consumptive on CAMS assessments it will be recorded as '0' in the Environment Agency CAMS ledgers.

The main requirement of control and monitoring:

- Ensuring flow in the depleted reach is maintained, on a failsafe basis
- That Hands-Off Flow is complied with
- The assessment of flow through the hydropower plant.

8.2. Ensuring Compliance

Flow in the depleted reach can be maintained in a number of different ways, and will need to be suited to the specific site requirements. This may be through a physical arrangement such as a notch or pipe in the weir set to pass the Hands-Off Flow or through a 'control level' head over the weir and the use of a Gauge Board. Regular monitoring of the level will be required to demonstrate compliance with licence conditions. Electronic control systems monitoring the water level and controlling flow to, and operation of the hydropower unit should record the water level data for compliance purposes.

Hands-Off Flow levels should trigger a reduction in abstraction and eventually a cessation of abstraction and generation.

The measurement of flow in open channels is well documented (ref BS3680) and will normally be converted to 'control levels'.

There are four methods for assessing that the approved abstracted flow regime is being adhered to (see Table 3). A developer can propose any of these providing the project is within the limits shown.

Flow Monitoring Method	Limits
1. Estimate the abstracted flows from the generation records in accordance with the procedures set out in the Appendix. Determine the residual flows achieved by comparison with actual flows recorded near the intake to the project. This method is most applicable where real time flows are used to control a 50/50 flow split.	There must be an existing automatic flow metering station near the intake to the project.
2. Open channel flow measurement by an automatic recorder of the residual flow e.g. a 'V' notch in the weir and water surface level recorder.	none
3. A fixed diversion that physically guarantees that the approved minimum residual flow cannot be diverted to the turbine e.g. a by pass pipe or notch in the weir.	none
4. An agreed minimum water level at the intake which physically ensures the agreed residual flow is maintained.	none

Table 3 Flow monitoring methods to ensure compliance with Hands-Off Flows and flow in the depleted reach.

8.3. Assessment of flow through the hydropower plant

Assessment of flow through the hydropower plant can be achieved through conversion of the records of electricity generated. The conversion factor for each site will need to be calculated as detailed in the Flow Measurement Analysis guide (available on request).

As the hydropower abstraction is non-consumptive, information is only required to ensure compliance with the Hands-Off Flow conditions, and that abstraction conforms to the agreed abstraction rules.

For small hydropower projects that have a total generated capacity less than 5 MW the abstracted volumes can be monitored using the generation records in accordance with the procedures set out in the Flow Measurement Analysis guide. Other forms of flow measurement may be proposed by developers and approved providing their accuracy and reliability are at least as good as the generation record method.

For hydropower projects that have a total generated capacity less than 5 MW there is no specific requirement to monitor abstracted volumes.

9. FISH PASSAGE

9.1 Upstream Passes

Where there is an existing upstream fish pass, approved or otherwise, it is expected that the effectiveness and efficiency of that pass will be maintained by any hydropower development or improved where they are not satisfactory.

On migratory salmonid rivers, or designated recovering and rehabilitated salmonid rivers, where there is currently no fish pass, then normally it is expected that one will be required. On other rivers a fish pass may be required where it is considered that any reduction in fish passage may cause deterioration in ecological class status or that the absence of one is preventing achievement of good ecological status.

Circumstances requiring a fish pass

- Under the Salmon and Freshwater Fisheries Act, in waters frequented by salmon and sea trout, a pass will be required if:
    - a new impoundment is constructed, or
    - if an impoundment is rebuilt or reinstated over half its length, or
    - if an existing impoundment is altered physically, or
    - as a result of flow reduction so as to create an increased obstruction.

  Where an existing impounding structure is partially passable, removing flow from it to a hydropower scheme will in most circumstances reduce passage for fish. It may prevent passage altogether, or more likely reduce the window of opportunity for fish to pass.
- As a condition of the abstraction licence, impoundment licence or Flood Defence/ Land Drainage consent, if the species of fish present will experience increased difficulty completing their life cycles as a result of the installation, and which may lead to a deterioration in ecological status.
- Other legal obligations may be applied where sites or species affected have nature conservation designations e.g. under Habitats Directive, SSSI or are the subject of European conservation plans e.g. eel.
- Where fish passage will be impeded, such as in any long depleted reach, a fish pass may be required at the powerhouse.

It is only possible to provide comment on a case by case basis, and the developer will need to consult the local fisheries staff in order to establish whether an upstream fish pass will be a requirement.

If a fish pass is required, the design must be approved by the Environment Agency.

Where a fish pass is already present, or where a fish pass is provided by the scheme, we expect the downstream fish pass entrance and the discharge from the turbine(s) to be co-located, since this will usually enhance attraction to the vicinity of the pass. Establishing a competing flow would reduce fish pass effectiveness and efficiency, and will not be acceptable.

Where they are co-located, a suitable pass attraction flow is around 10 per cent of maximum turbine flow (and subject to the minimum flow required to make any particular type of pass operational hydraulically and biologically).

Where a fish pass is present it may be considered to be part of the residual flow.

Where a fish pass is not included in a scheme, the Environment Agency may require sufficient flow and a suitable location be reserved for the installation of a fish pass in the future.

9.2 Environment Agency Upstream Fish Pass Manuals

The Environment Agency has produced a fish pass manual to guide its own staff and developers. A copy on CD can be obtained from the National Fish Pass Officer[1]

The manual contains background information on fish passes and the requirements of different species of fish, gives examples of designs which may be suitable in different circumstances and includes details of the approval process which the Environment Agency will use to formalise the approval on a site specific basis.

A separate Best Practice Guide is also available for eel & elver passes, and is available on the Environment Agency website[2].

Developers are advised to consult the Environment Agency early in the development process to discuss the need for a fish pass. If the need is identified, developers are advised to submit their ideas at the concept stage to avoid the risk of abortive effort being spent on creating detailed proposals which may prove unsatisfactory.

9.3 Tailrace screens

Upstream migrating fish may be diverted or delayed if they are attracted into tailrace channels. They must therefore be prevented from doing so.

Either physical or electric barriers are acceptable for salmonid or coarse fish waters. Physical barriers are preferred if there is a risk that fish could enter the turbine from the tailrace.

The following rules apply:

Form of Barrier	Comments
Electric barrier	These should only be used where fish have been completely excluded from passing downstream through the turbines. Graduated field types are preferred. It is essential that they are operated 100 per cent of the time, even when the hydro plant is not running otherwise fish may enter the turbines and be present when they re-start. An externally visible indicator light or other means required to confirm that barrier is switched on. Voltage field should be checked annually in the water using a suitable test device and compared to specification in order to ensure that electrodes are in good condition.
Physical Bar Screens	40 mm spacing for salmon, 30 mm where sea trout are present. Screens must be constructed from wedge wire, square or oblong metal bars - round or oval bars are more likely to gill fish.

Placement of screens should be close to the edge of the river bank at the point of return of the turbine discharge to the river or lake.

Where fish are permitted to pass through turbines the design of the downstream screens must take account of the need for fish to pass in the downstream direction, while also acting as screens to prevent ingress of the upstream migrating fish.

[1] National Fish Pass Manual
[2] Eel and Elver passes

10. FISH SCREEN REQUIREMENTS AND DESIGN

This section provides procedures for determining the default fish screen requirements when designing a small hydro scheme. Some regional variation in design requirements reflects the effect of climate and geology on fish growth, notably that salmonid smolts tend to be smaller in colder or more oligotrophic (nutrient poor) areas. Further information can be found in the Environment Agency Best Practice Guide for Intake and Outfall Fish Screening [3]. The advice given here may not apply to areas with special conservation designations, e.g. under the EC Habitats Directive, for which special advice should be sought from Natural England and CCW .

It is important to note that good downstream passage design is a combination of effective screening and diversion, and a safe bywash route.

10.1 Intake Screening

The ‘fish friendliness’ of low-head hydropower generating equipment follows

High Impact				Low impact
→	→	→	→	→
Pelton & other impulse types	Crossflow	Kaplan /Francis	Traditional Water wheels	Archimedes screw

Generally, the smaller the turbine size the more damaging it is likely to be. Traditional water wheels are assumed to be benign, but the same may not be true of modern wheels. Screening requirements vary for fish species and age.

Pelton and Impulse turbines, normally used on high head systems, have almost nil survival rate for entrained fish. In most cases a 3mm screening drop through, self cleaning screen is used to prevent the entry of debris that will damage the turbine. 3mm screens will prevent the entry of salmonid fry, under-yearling coarse fish and lamprey ammocoetes. Where these species are not present it may be acceptable to use 6mm screen to exclude salmonid parr, young of year coarse fish or silver eels.

Crossflow turbines are commonly used on low head schemes. The shape of the turbine and blades and the high rotation speed make the survival rate for entrained fish very low, and they need to be excluded by screening. 10/12.5mm screens will be required to prevent the entry of salmon and sea trout smolts. Where salmonid parr, young of year coarse fish or silver eels are present or occur at the site, a 6mm screen is recommended during this period.

Smaller propeller turbines (<1.5m3/sec) will require similar screening specification to crossflow turbines especially where autumn migrating smolts and juvenile trout are present. The Environment Agency will endeavour to provide indications or evidence of this where it is available.

[3] Turnpenny, A.W.H. and O’Keeffe, N. (2005). Best Practice Guide for Intake and Outfall Fish Screening. Science Report SC030231. The Environment Agency, Bristol, UK.

Larger Kaplan and Francis turbines are considered to be safer for fish passing through. The damage rate for fish passing through a propeller type of turbine depends on the size/capacity of the turbine and the length and species of fish at risk. Eels are therefore at particular risk, and for larger female silver (out-migrating phase) eels, a 12.5-15mm physical screen is required. Lower down in the catchment, where there may be a preponderance of smaller male eels, a 10mm screen may be necessary.

Modern variants of Francis turbines have snail-shaped feed pipes and relatively fast runner speed are the least "fish-friendly" but unlikely to be found on low head run-of-river schemes with the exception of the smaller "polymer" turbines. It is considered that fish will have a poor survival rate if they were to pass through these and therefore screening similar to that recommended for the crossflow turbine is required.

The older type of low-head Francis turbine is better for fish, but are no longer manufactured. Where re-furbished ones are used, a 10/12.5mm screen is necessary to exclude smolts, other similar sized fish and eels.

Where large Kaplan turbines are proposed, a risk assessment on screening will be required if the default size of screen is not being used (see Environment Agency Best Practice Guide for Intake and Outfall Fish Screening).

Archimedean screw turbines have been demonstrated to cause minimal damage to fish, <u>provided</u> appropriate protection to the leading edge of the screw is applied. For turbines with a tip speed <3.5 m/sec a hard rubber extrusion should be used; for turbines with a greater tip speed a compressible silicone extrusion is required.

Behavioural screens – louvre bar, acoustic, bubble and strobe – are sometimes advocated. A single type is unlikely to provide sufficient protection where a variety of species are present, but combined with other measures they can be effective. Where such screens are proposed a satisfactory supporting Risk Assessment will need to be carried out by the developer. Further details are available in the Environment Agency Best Practice Guide for Intake and Outfall Fish Screening [4].

The default screen requirements are set in Figure 5

The use of the screen sizes laid out is also dependent on meeting the other criteria laid out in section 10.2 and 10.4 regarding approach and escape velocities and by-wash provision.

Tailrace screening is covered in section 9.3

[4] Turnpenny, A.W.H. and O'Keeffe, N. (2005). Best Practice Guide for Intake and Outfall Fish Screening. Science Report SC030231. The Environment Agency, Bristol, UK.

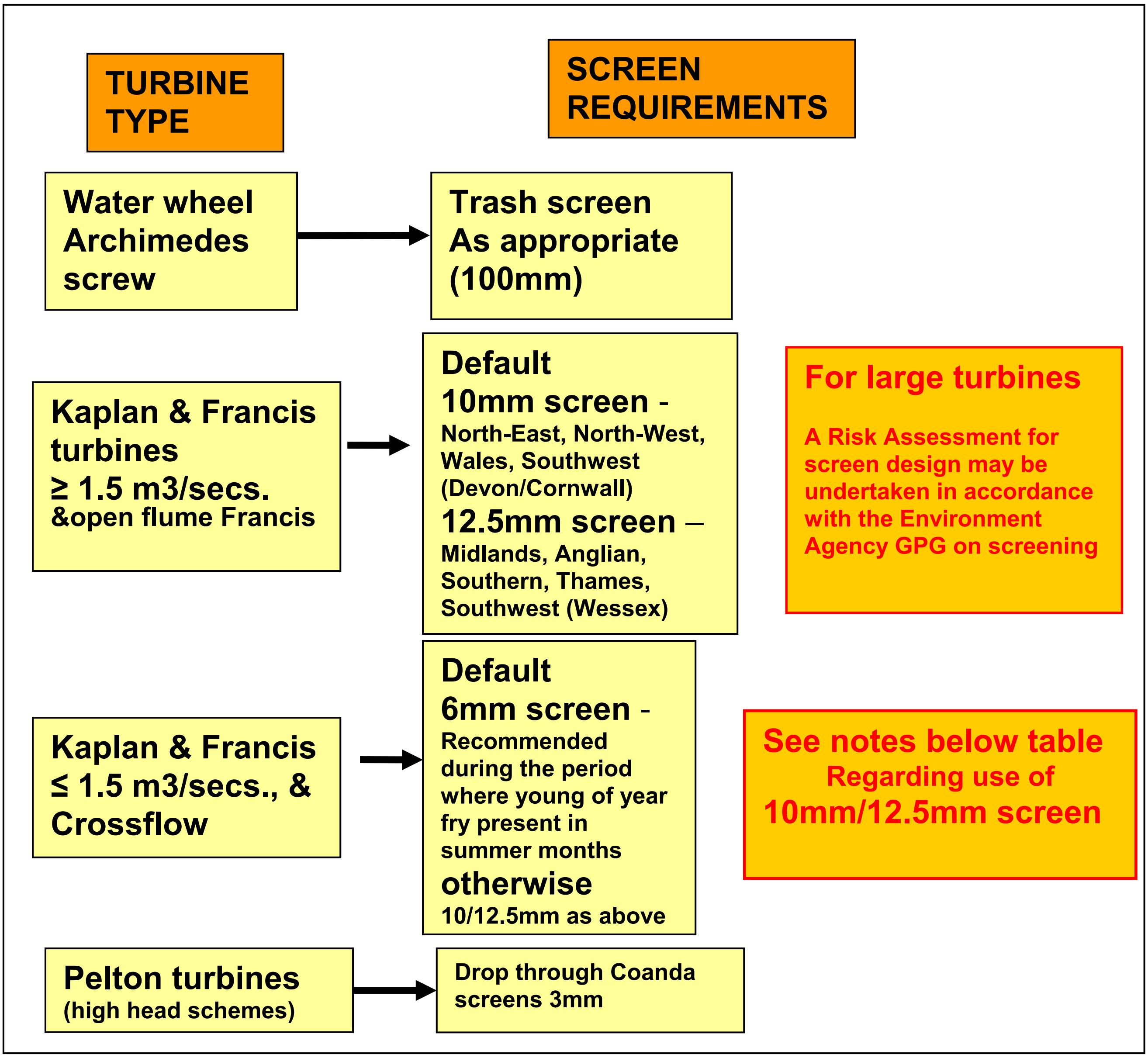

Figure 5 Turbine type and default screen requirements

Notes to Figure 5
Figure 5 gives default screening spacing depending on the threat different turbine types pose to fish populations. Developers may, however, wish to propose different spacing based on the specifics of their scheme design and local environment. Any such proposal must be accompanied by a Risk Assessment, which should consider the species and sizes that need protecting, the mortality rates associated with the turbine to be deployed, and the overall impact the proposed scheme may have on the fish population.

There are a number of mitigating factors that may be deployed that may be compatible with using an over spaced screen (ie a screen that has wider apertures than specified in Figure 5). These factors include:

- Placing the screen at a diagonal angle to the flow, guiding the fish to the lower end of the diagonal and towards a bywash with sufficiently high flow.
- The use of behavioural barriers, such as bubble curtains, which have been shown to be effective deterrents when deployed in combination with a physical screen.

- In the case of Kaplan turbines, larger turbines move slower and may have lower mortality rates for smaller fish, reducing the overall risk . Evidence of this would be required.

A number of hydropower schemes with Crossflow turbines are operating with 10mm screens, but their effectiveness requires confirmation.

The Environment Agency recommends that 6mm screens are installed if there is evidence that there are, and during the period when young of year fry are present.

The Environment Agency is committed to undertake investigations to demonstrate the effectiveness of different size screens on the exclusion of fish fry at hydropower sites and will review the screening requirements in light of our findings.

If consent is given by the Environment Agency for a hydropower developer to install 10/12.5mm screen, they may need to be replaced (at the developers expense) within a year of notice being given following evidence from its investigations being provided by the Environment Agency that these have failed to provide adequate protection.

10.2 Screen Approach Velocity

The **approach velocity Ue** (also known as ‘escape velocity’) for screen design purposes is defined as the velocity 10 cm upstream of the screen, perpendicular to the screen face. Where installed in a headrace, the screen should be angled diagonally across the flow, allowing low approach velocity even when the axial channel velocity Ua in the headrace is high. This has the added benefit of guiding fish towards the bywash entrance (Figure 6). Note that where multiple species are being considered the lowest common acceptable approach velocity will need to be used.

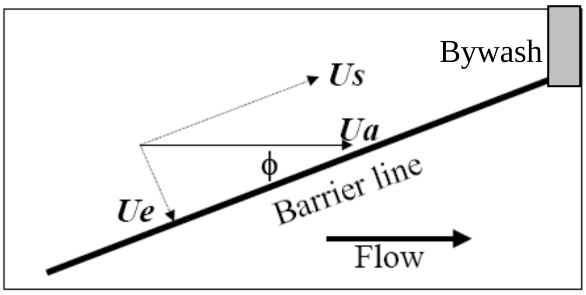

Fig 6 Flow velocity components in front of an angled fish barrier.

***Ua* is the axial channel velocity, *Ue (=UsinΦ)* is the fish escape velocity and**

***Us (=UcosΦ)* is the sweeping velocity component along the face of the screen.**

Salmonid

The maximum acceptable design velocity of approach towards any part of a screen is 0.6 m/s.

Coarse fish & Shad

The maximum acceptable design velocity of approach towards any part of a screen is 0.25 m/s.

Eel

The maximum acceptable design velocity of approach (escape velocity) towards any part of a screen is 0.50m/s.

Lamprey

The maximum acceptable design velocity of approach (escape velocity) towards any part of a screen is 0.30m/s.

10.3 Accounting for Debris

The blocking of the screen with debris will increase velocities in practice, particularly where the screen is at right angles to the flow. This means that an allowance must be made for some blocking when sizing the screens, such that the target approach velocity is not exceeded when screen performance is reduced by the accumulation of debris. The inclusion of an automatic screen cleaner will improve performance so that the additional area of screen required can be less. It is assumed that where screens are to be cleared manually the target approach velocity will need to be maintained with 50 per cent screen blockage, while with automatic screen cleaning it will need to be maintained with 10 per cent screen blockage.

10.4 Screen bywash

A screen bywash is required wherever the intake screen of the hydropower scheme is not located in the normal course of the river (i.e. it is within the headrace). For a diagonal screen alignment, the bywash entrance should be located at the downstream end of the screen to take advantage of the guidance effect. If the by-wash is well-designed, a typical bywash flow would be in the range 2-5 per cent of the scheme design flow. A higher proportion may be needed if by-pass design is poor e.g. aligned perpendicular to flow, located away from the end of the screen, poor hydraulic conditions at by-wash entry etc. Good screen by-wash design will include a sweeping velocity increasing smoothly into the by-wash entrance, adequate entrance size (minimum 0.4-0.5m wide and deep), avoidance of sharp shadows particularly at the entrance, a smooth and safe by-wash conduit to avoid damage to fish in transit, and a safe delivery to the downstream.

It is acceptable to use some types of fish pass as the bywash where they can be suitably positioned. Larinier, vertical-slot, pool and traverse or nature-like fish passes are suitable for this purpose. However, Denil, Alaskan A, or side-baffle passes might cause abrasion damage to fish and are therefore not suitable for joint use.

The bywash return point should be sufficiently deep to prevent fish being stranded or damaged on impact, with a depth at least 25 per cent of the differential head and no less than 0.9m.